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Assessing moisture content on the surface of mortar samples from hyperspectral imaging

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Abstract

Hyperspectral imaging represents an electromagnetic spectrum for each pixel in the image of a structural surface. The characteristic wavelength of the spectrum at reflectance valleys or absorption peaks can be used as a spectral feature for certain chemical detection. In this study, spectral reflectance characteristics of mortar samples are extracted to assess the reduction of moisture on the surface of mortar samples during the cement hydration process. The test results indicate that the reflectance increases and the absorbance decreases because water is reacted and less light will be absorbed during the hydration process. The average absorbance between 1923 nm and 1983 nm in wavelength gradually decreases with the mortar curing time. This feature parameter can be used to evaluate the mortar hydration process.

1. Introduction

Concrete is the most widely used material in buildings, bridges, dams, tunnels, pavements, runways and roads due to its high durability and resistance to weathering and natural disasters. When concrete structures like pavements are built on site, usually a minimum curing period is required to ensure that the concrete can attain the specified compressive strength before the road is open to the traffic (ACI Committee 301, 1972). It is necessary to understand the minimum curing period of the concrete to reduce the economy cost caused by the shut-down of traffic. The pull off test and the maturity method are used to determine the strength of concrete in situ but both methods need to establish the reference curves. The concrete curing process occurs immediately after finishing. The cement hydration consumes free water in the pore solution and generates hydration products like C-S-H gel and calcium hydroxide (Liu et al., 2017). Therefore, the reduced moisture content can be used as a sign to predict the increase in the strength of concrete. Backscattered electron imaging has been used to study the free-water content in concrete through measuring the concrete porosity (Sahu et al., 2004; Wong et al., 2019). As this method can only be implemented in laboratory, other techniques are needed to determine the water content of concrete on site without destroying it.

Hyperspectral imaging has been utilized in mineral identification, vegetation classification, and natural resource exploration (Zaini et al., 2016; DeTar et al., 2008; Tian et al., 2012). These applications are based on higher level of spectral resolution in hyperspectral images to identify the specific property related to the materials. The hyperspectral imaging can obtain continuous light intensity spectrum for each pixel in the image of a scene, which can be used to identify the objects in the scene with great precision and detail. The composition of carbonate and clay minerals on the Portland cement-grade limestone surface can be estimated through characterizing the wavelength position and depth of the absorption spectra (Zaini et al., 2016). The airborne hyperspectral imaging has been taken on the seeded and nearly bare soil to characterize the in-field distribution of soil components (DeTar et al., 2008). The oil-gas reservoirs are detected through analyzing the absorption bands in hyperspectral images for oil-gas exploration (Tian et al., 2012).

In this study, hyperspectral imaging is used to obtain the characteristic wavelengths at absorption peaks of an electromagnetic spectrum for each pixel in the image of a concrete surface. The reflectance can be related to the moisture content on the mortar sample surface, thus providing an effective indicator for mortar hydration process. The mortar sample are cured for one day and demolded for hyperspectral scanning for 14 days. The absorption peaks bands around 1900 nm is used to detect the change of moisture content on the mortar sample surface.

2. Materials

A Type I Portland cement was used. Table 1 lists the mix proportion of the mortar. The water-to-cement ratio was 0.6. Freshly mixed mortar was cast into cubic molds with dimensions of 50 mm by 50 mm by 50 mm to prepare specimens. After casting, the specimen was covered with wet burlap and plastic sheet to prevent surface cracking due to plastic shrinkage. The specimen was demolded after 24 hours and hyperspectral camera was used for sample surface scanning in the first 14 days.

Table 1. Mortar mixture proportion

Water	0.6
Ordinary Portland cement	1.0
Missouri river sand	3.09

3. Experimental Study

The headwall Hyperspec VNIR-SWIR sensor is used to scan the mortar samples in this study. The co-aligned VNIR-SWIR sensor has a broad wavelength range of 400-2500nm, of which the VNIR sensor has a spectral range of 400-1000 nm and the SWIR sensor has a spectral range of 900-2500 nm. The spectral resolution is 2.2 nm for VNIR sensor and 6 nm for SWIR sensor. For the detection of surface moisture content, the camera is set to the SWIR sensor for sample surface scanning. The distance of mortar samples to the light source (LED illumination) was 0.5 meter and the camera was set 1.2 meter to the front surface of mortar samples as shown in Figure 1. The camera was installed on the tripod and a laptop was connected to the camera with Hyperspec III software to control its rotation and collect images. Before capturing images, the first step is to calibrate the camera with the collections of dark reference and white reference. The dark reference is used to measure the electric current in the system, so the software deducts that from the scan data to eliminate noise; the white reference is used to get the white balance. The dark reference was collected through placing the supplied lens cap over the camera lens while the white reference was collected through aiming the camera lens at a reflective grey canvas. Exposure time and frame period were also adjusted so that 60% of saturated light intensity was detected using the grey canvas. If the light intensity detected by the camera is too low, significant noise will appear in the data, which cannot be mathematically corrected. Besides, a certain amount of rotation angles need to be ensured during scanning so that the camera can cover the whole surface area of the sample.

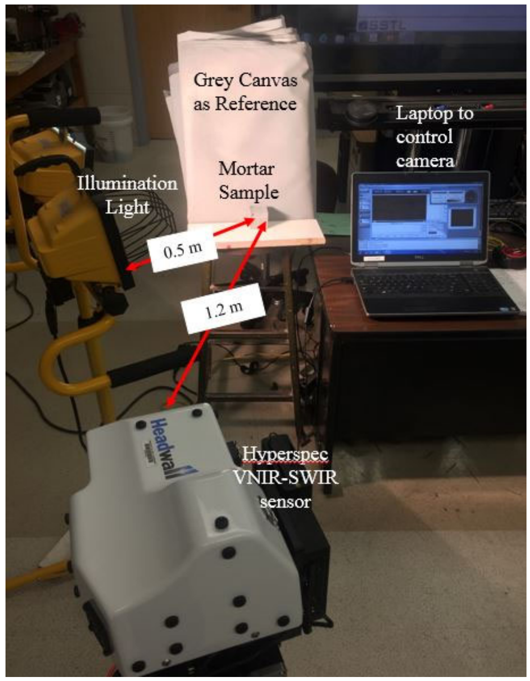

Figure 1. Experiment setup.

After demolding of the cube samples, the samples were scanned each day until the 14th day. After scanning, the files are transferred from the camera to the computer and SpectralView is used to extract the reflectance of each pixel on the images. For the image pre-processing, the dark reference is used to eliminate the background noise and increase the signal to noise ratio. The white reference is used to calculate the reflectance of the light. The reflectance can be calculated by:

$$R=I/I_s \tag{1}$$

where I_s is the reflected light intensity of the standard grey canvas (with 50% reflection);I is the reflected light intensity of the sample. The absorbance of the light can be deduced by:

$$A=log(1/R) \tag{2}$$

For each scanned sample surface, twenty spectra were extracted from the selected twenty points and the mean spectrum is used for following analysis.

5. Results and Discussion

The hyperspectral image of a mortar specimen after dark and white reference deductions is shown in Figure 2. The average reflectance spectra over a 50 mm × 50 mm (2500 pixels) surface area of the mortar specimen in 14 days are presented in Figure 3 at a wavelength range of 950 nm - 2350 nm. Previous studies of cement-based materials have shown that the wide absorbance band around a wavelength of 1900 nm is caused by the combination tone of H_2O (Walling et al. 1989). The overall reflectance of the sample surface shows an increasing trend since the water is reacted during the hydration process. As less water is left on the sample surface, less light will be absorbed, increasing reflectance. Figure 4 shows the mean absorbance spectra of the mortar samples up to 14 days. The absorbance spectrum gradually decreases with curing time.

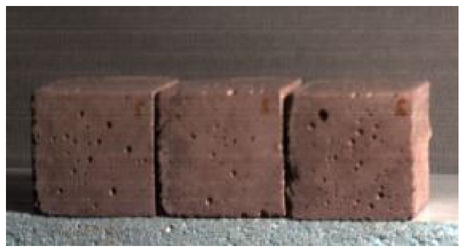

Figure 2. The hyperspectral image of mortar specimens after dark and white reference deductions.

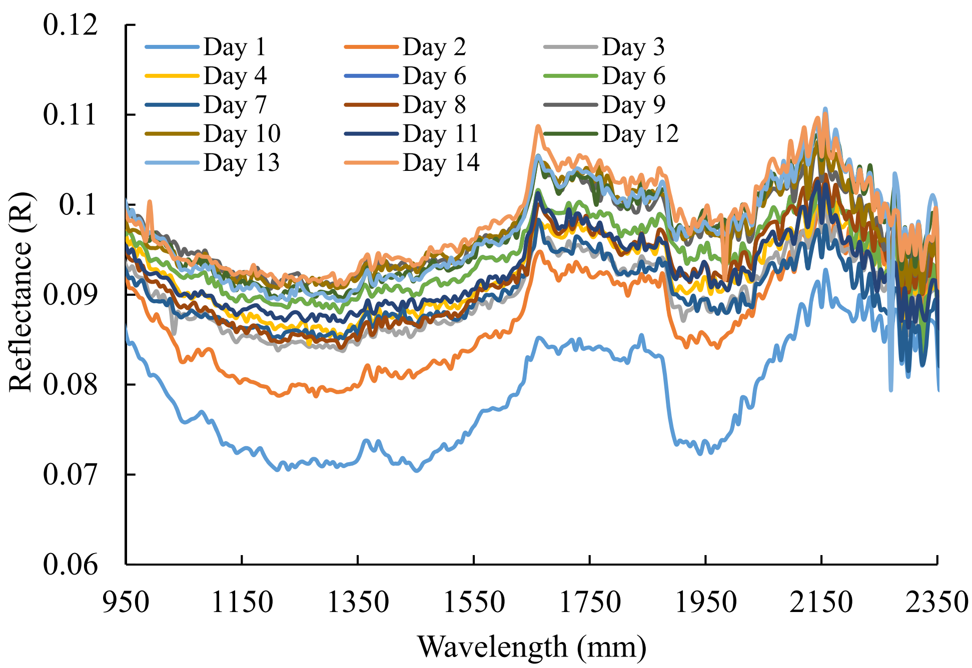

Figure 3. The average reflectance spectra of the mortar sample over a wavelength of 950 nm - 2350 nm when the sample is cured up to 14 days.

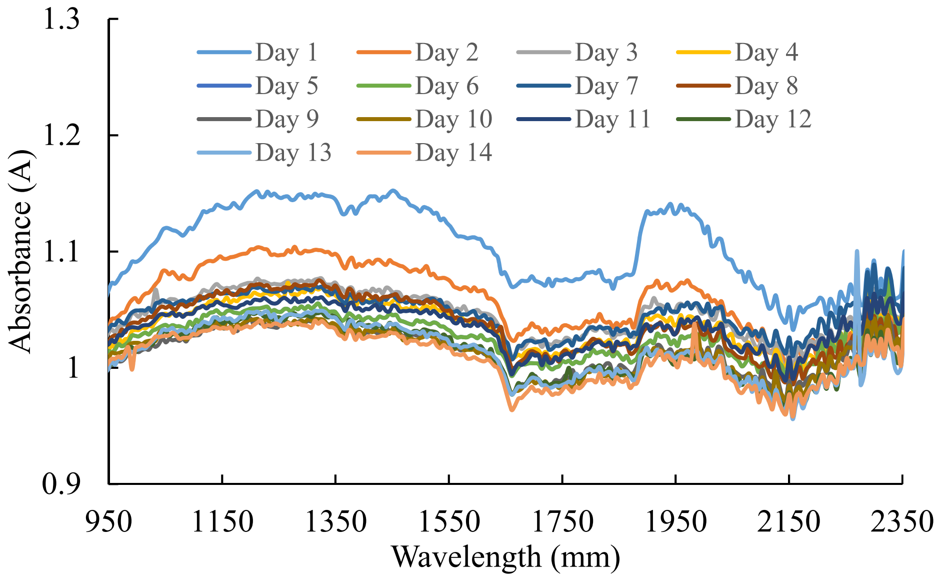

Figure 4. The average absorbance spectra of the mortar sample over a wavelength range of 950 nm -2350 nm when the sample is cured up to 14 days.

Here, a difference absorbance dA (1923-1983) is defined as the average absorbance over a wavelength range of 1923 nm to 1983 nm. This index represents the extent of hydration process. Figure 5 shows the difference absorbance dA (1923-1983) with the curing time. In general, the difference absorbance shows a decreasing trend over 14 days following a logarithmic curve. This result indicates a rapid hydration process at the beginning and a gradually decreasing hydration at 14 days.

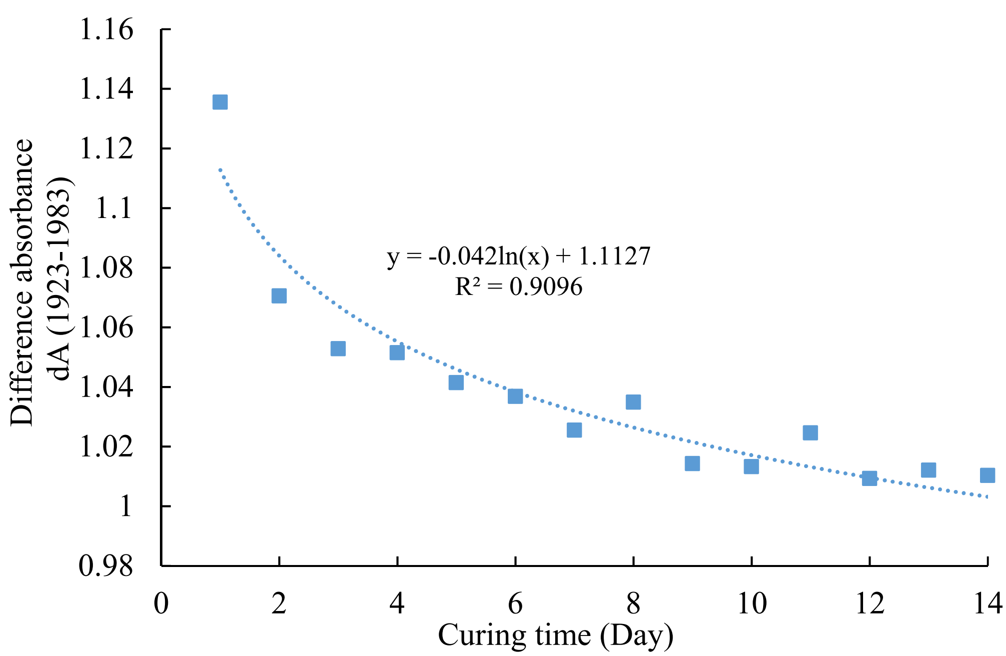

Figure 5. The difference absorbance dA (1923-1983) decreasing over curing time in 14 days.

6. Conclusions

Based on the spectral data obtained from the hyperspectral camera, the following conclusions can be drawn:

Hyperspectral shapes and intensities appear closely related to the change of moisture on the surface of mortar samples. Hyperspectral features are promising for the detection of moisture and thus the strength of early age mortar.

The reflectance on the surface of a mortar sample gradually increases while the absorbance gradually decreases due to its cement hydration process. The difference absorbance dA (1923-1983) gradually decreases with the increase of mortar curing time, which can be used to evaluate the process of mortar hydration.

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